Chapter 1 : Ultimate Limits of Fabrication and Measurement (Nato Science Series E:) - | SlugBooks

Ultimate Limits of Fabrication and Measurement brings together a number of leading articles from a variety of fields with the common aim of ultimate miniaturisation and measurement.

This electronic reprint is available on the web at http: Introduction Experimental[7] and theoretical[4, 6, 8, 21, 22] work both support the idea that we will be able to fabricate precise molecular structures such as molecular logic elements by positioning individual atoms and molecules. However, even the ability to make and interconnect a few atomically precise logic elements will have limited impact when we must make and interconnect at least trillions of logic elements to surpass projected future lithographic capabilities. The only demonstrated method of mass producing complex highly precise structures at a low cost per kilogram is by programmable self replicating systems as exemplified by potatoes, wheat, wood, etc. Electronics are not cheap: Biological computers, despite their many virtues, have high error rates, millisecond logic delays and meter-per-second signal propagation speeds: While the design and development of non-biological programmable self replicating systems suited to the manufacture of complex high performance computer systems as well as a range of other high precision products might at first appear daunting, there has been much theoretical work in this area. More recent work suggests that further simplifications are possible and that research to determine the simplest and most easily manufacturable programmable self replicating system should be pursued. General manufacturing systems Because biological self replicating systems are so ubiquitous it is common to assume that their specific properties and idiosyncratic features are an inherent requirement for all self replicating systems. However, programmable self replicating systems designed for manufacturing need bear little resemblance to biological systems. We shall call such non-biological systems general manufacturing systems. In this article we highlight the differences between biological systems and general manufacturing systems. Design concepts for general manufacturing systems have been discussed for many years [10, 27, 28], and their utility in manufacturing has been emphasized recently [4, 5, 6, 18]. These proposals draw on a body of work started by von Neumann[27]. A wide range of methods have been considered[10, particularly pages et sequitur "Theoretical Background"]. The von Neumann architecture for a self replicating system is the ancestral and archetypal proposal[24, 27]. The universal computer contains a program that directs the behavior of the universal constructor. The universal constructor, in turn, is used to manufacture both another universal computer and another universal constructor. Once construction is finished the program contained in the original universal computer is copied to the new universal computer and program execution is started. Von Neumann worked out the details for a constructor that worked in a theoretical two-dimensional cellular automata world parts of his proposal have since been modeled computationally[24]. The constructor had an arm which it could move about and which could be used to change the state of the cell at the tip of the arm. By progressively sweeping the arm back and forth and changing the state of the cell at the tip, it was possible to create "objects" consisting of regions of the two-dimensional cellular automata world which were fully specified by the program that controlled the constructor. The kinematic constructor was a robotic arm which moved in three-space and which grasped parts from a sea of parts around it. These parts were then assembled into another kinematic constructor and its associated control computer. An important point to notice is that self replication, while important, is not by itself an objective. A device able to make copies of itself but unable to make anything else would not be very valuable. It is this ability to make any one of a broad range of structures under flexible programmatic control that is of value. The ability of the device to make copies of itself is simply a means to achieve low cost, rather than an end in itself. The computer and constructor both shrink to the molecular scale, while the constructor takes on additional detail consistent with the desire to manipulate molecular structures with atomic precision. The molecular constructor has two major subsystems: The positional capability might be provided by one or more small robotic arms, or alternatively might be provided by any one of a wide range of devices that provide positional control[9, 15]. The emphasis, though, is on a positional device that is very small in scale: The tip chemistry is logically similar to the ability of the von Neumann universal constructor to alter the state of a cell at the tip of the arm, but now the change in "state" corresponds to a change in molecular structure. That is, we must specify a set of well defined chemical reactions that take place at the tip of the arm, and this set must be sufficient to allow the synthesis of the structures of interest. It is worth noting that current methods in computational chemistry are sufficient to model the kinds of structures that will appear in a broad class of molecular machines, including all of the structures and reactions needed for some assemblers[16, 20, 21, 22] 4. This is not a logical necessity in a general manufacturing system. If we separate the "constructor" from the "computer," and allow many individual constructors to receive broadcast instructions from a single central computer then each constructor need not remember the plans for what it is going to construct: This approach not only eliminates the requirement for a central repository of plans within the constructor which is now the component that self replicates , it can also eliminate almost all of the mechanisms involved in decoding and interpreting those plans. The advantages of the broadcast architecture are: This general approach is similar to that taken in the Connection Machine[14], in which a single complex central processor broadcasts instructions to a large number of very simple processors. Storing the program, decoding instructions, and other common activities are the responsibility of the single central processor; while the large number of small processors need only interpret a small set of very simple instructions. It is interesting to view the cell as using the broadcast architecture with the nucleus as the "central computer" broadcasting instructions in the form of mRNA to perhaps millions[29] of ribosomes. Drexler has proposed immersing the constructor in a liquid or gas capable of transmitting pressure changes and using pressure sensitive ratchets to control the motions of the constructor[6]. If each pressure sensitive ratchet has a distinct pressure threshold so that pressure transitions around the threshold cause the ratchet to cycle through a sequence of steps while pressure changes that remain above or below the threshold cause the ratchet to remain inoperative then it is possible to address individual ratchets simply by adjusting the pressure of the surrounding fluid. This greatly reduces the complexity of the instruction decoding hardware. Differences between biological systems and general manufacturing systems General manufacturing systems are likely to be very different from biological systems. First, general manufacturing systems aim to produce products with the best achievable performance and capabilities, e. Biological systems, based largely on protein, are unlikely to achieve this objective. Second, it seems likely that the indirect and circuitous routes by which biological systems control three dimensional structure e. Third, the error rates in biological systems are relatively high. It should be feasible to substantially reduce these error rates and produce systems and products with superior reliability, performance, materials properties, etc. Fourth, biological systems are not designed to allow rapid reprogramming. A potato cannot readily be reprogrammed to make a steak. General manufacturing systems should be able to respond rapidly to changing requirements by changing what is manufactured. Fifth and last at least in this paper , we want general manufacturing systems to be free of extraordinary risks. More than proteins The greater the diversity of products a manufacturing system can make, the more valuable it is. If it can only make biological products, its value is reduced. Consider the problem of building high performance computers. While biological computers e. Note that the poor performance of the underlying hardware increases our respect for an architecture and software which manage to wring such amazing feats from such slow and unreliable components. It seems certain that future computers will have the smallest possible logic elements, built with the highest possible precision and at the lowest possible cost. This should result in logic elements which are molecular in both size and precision, assembled in complex and idiosyncratic patterns. Diamond, with its wide band gap, excellent thermal conductivity, large breakdown field and high mobility would provide an excellent semiconductor for such future devices[12]. Molecular-sized logic elements packed densely in three dimensions will produce significant heat; an often overlooked problem in molecular logic proposals. This problem can be dealt with by using thermodynamically reversible logic[19 and references therein]. Biological structural materials are also far from ideal. Diamond has a strength to weight ratio over 50 times that of steel, and properly engineered materials in the future should be able to approach this strength and yet resist fracturing. Nothing in biology approaches this. The chemical reactions involved in the synthesis of diamond today are very different from those involved in making proteins[1, 2, 11]. Reactions proposed for the atomically precise synthesis of diamondoid structures involve highly reactive compounds in an inert environment[6, 21, 22]; a very different approach than that taken in biological systems. For strength and stiffness, materials using boron, carbon and nitrogen are superior[3]. Diamond is also an excellent candidate material for future electronic devices. If we limit general manufacturing systems to proteins we will exclude a vast range of very valuable products. We will almost certainly wish to make diamond and diamondoid products. This implies the use of reactions and conditions very different from what we see in biology today. Positional Control Besides using non-biological materials, general manufacturing systems are likely to make extensive use of positional control, i. The Stewart platform[9, 13, 25, 26] seems ideal for providing positional control at the molecular level. The basic Stewart platform is an octahedral structure in which one triangular face is designated the "base," the opposing face is designated the "platform," and six adjustable-length struts which lie along the six edges of the octahedron which are between the base and platform control the position of the platform. Within an allowed range of motion it provides complete control over the position and orientation of the platform with respect to the base; it provides high stiffness critical to positional control at the molecular scale ; all struts are either in pure tension or pure compression; and it is a simple design. This simplicity suggests that it might be feasible to self-assemble a Stewart platform e. The application of positional control at the molecular level appears feasible both theoretically and experimentally, and offers striking advantages in the manufacturing process. The reader is invited to consider the difficulties involved in manufacturing a car if positional control were prohibited in the manufacturing process. We can reasonably expect that the application of positional control to molecular synthesis will greatly extend the range of things that can be made[21]. It will also result in artificial systems that are very different from the biological systems with which we are familiar. Reduced error rates Another likely difference is in the error rates tolerated during assembly. The achievable error rate limits the range of options that can be pursued and in particular limits the feasible module size. A "module" is here viewed as an assemblage which has a relatively high probability of being manufactured correctly and of functioning correctly, and hence can be discarded in its entirety if there is any failure anywhere within the module. When error rates are high, the module size must be small. If the module size were large in the face of high error rates, the yield of correctly working modules would be unacceptably low and overall system function would be compromised. When error rates are low, the module size can be large. Protein synthesis has an error rate of roughly 1 in 10, [29] and we do not find proteins with tens of thousands of amino acids. There are well known methods of assembling unreliable logic elements into reliable computational systems. However, these methods result in reduced system performance and increased bulk. Experience with semiconductor devices supports the idea that the primary objective in the manufacturing process is to reduce the error rate to the lowest possible level, and only when further reductions are infeasible should redundant logic elements or other error- tolerant design approaches be adopted. Applying this philosophy to general manufacturing systems, we should first determine the lowest achievable error rate and then design modules of the largest possible size using the simplest and most efficient designs. It seems difficult to reduce error rates at the molecular level substantially below the levels caused by radiation[6]. Other error mechanisms e. This is in sharp contrast to the error rates and module sizes adopted in biological systems. We can reasonably expect that systems that take advantage of these low errors rates will involve designs and system functions that are very different from biological systems.

Chapter 2 : Self replicating systems and low cost manufacturing

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Chapter 4 : James Gimzewski

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Chapter 5 : Ultimate Limits of Fabrication and Measurement : J. K. Gimzewski :

Ultimate Limits of Fabrication and Measurement edited by M. E. Welland Department of Engineering, The University of Cambridge, Cambridge, U.K.

Chapter 6 : Christoph Gerber - Wikipedia

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